MULTI-SIZE DROPLETS GENERATION VIA SIDE-BRANCH MICROFLUIDIC CHANNELS

S. Xiong[1,2], L. K. Chin[1], Y. F. Yu[1], J. Q. Yu[1], Y. Chen[2], G. J. Zhang[2], G. Q. Lo[2], D. L. Kwong[2] and A. Q. Liu[1*]

[1] *School of Electrical and Electronic Engineering, Nanyang Technological University, SINGAPORE 639798*

[2]*Institute of Microelectronics, Agency for Science, Technology and Research, SINGAPORE 117685*

ABSTRACT

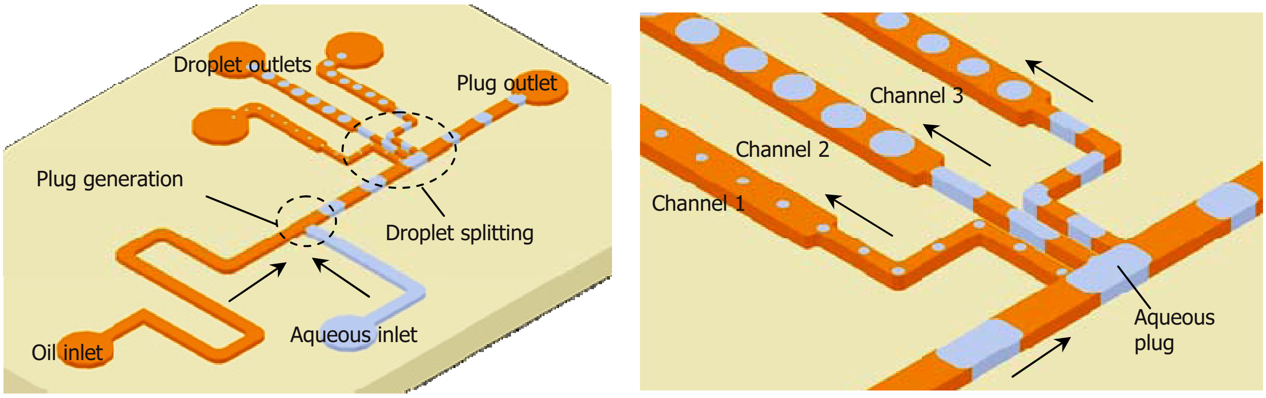
This paper reports a multiple monodispersed droplet generation using a side-branch structure in the microchannel. Water-in-oil plugs which are initially formed at a T-junction, are introduced to junction with three side-branch channels, then three organized streams of droplets are generated in the channels. The size of the droplets could be controlled by the size of the original plugs. The ability of generating multi-streams of monodispersed droplets from the same emulsions opens new possibilities for controlling and analyzing the biochemical reactions in a confined spaces.

KEYWORDS: Droplet array, Droplet splitting, Microfluidics

INTRODUCTION

Droplets in microfluidic systems are promising picoliter reactors in biomedical and biochemical applications as the reaction time and chemical concentration in each droplet can be precisely controlled. There is a high demand in generating monodispersed droplets with different sizes and solute concentrations for microanalysis in array. Previously, multiple bifurcating junctions were used to produce droplet array [1]. However, this design needs large device space and the range of the droplet size is narrow. To overcome these, we proposed a microfluidic system with side-branch structure that passively generates three organized streams of droplets concurrently from a single plug flow. The droplet size has wider tuning range and higher monodispersity.

DESIGN AND THOERY



(a) (b)

Figure 1: Schematic illustrations of (a) the passive droplet splitting system; and (b) the multiple-splitting branch for droplet splitting.

Figure 1 shows the schematic illustrations of the microfluidic chip for passive droplet splitting system. The system consists of a T-junction for plug generation and a side-branch for droplet splitting. Aqueous plugs are initially generated at a T-junction with immersion oil as the continuous phase. Subsequently, the aqueous plugs are split into different sizes of droplets when they pass through the side-branch.

For system modeling, a resistive circuit is designed as an analogy to the microchannel structure and shown in Fig. 2. By considering the relation between the flow resistance (R), pressure drop ($\Delta P = P_i - P_j$), and the volumetric flow rate (Q) of each

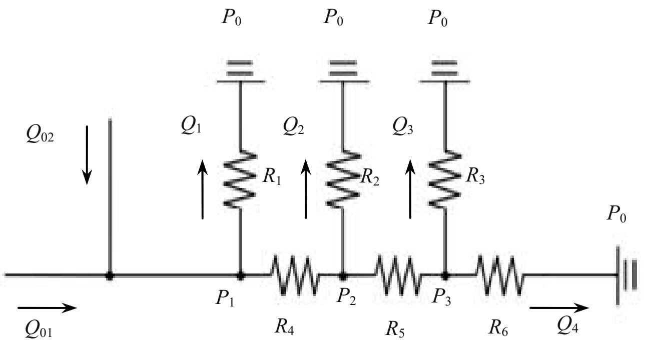


Figure 2: The schematic illustration of the resistive circuit which acts as an analogy for the microchannel structure design.

microchannel segment, the droplet size ratio can be derived. The flow resistance is calculated by the geometrical parameters of the microchannel [2]. The volume ratios of the droplets are expected to be equal to the volumetric flow ratios of each branch channel.

EXPERIMENTAL RESULTS AND DISCUSSIONS

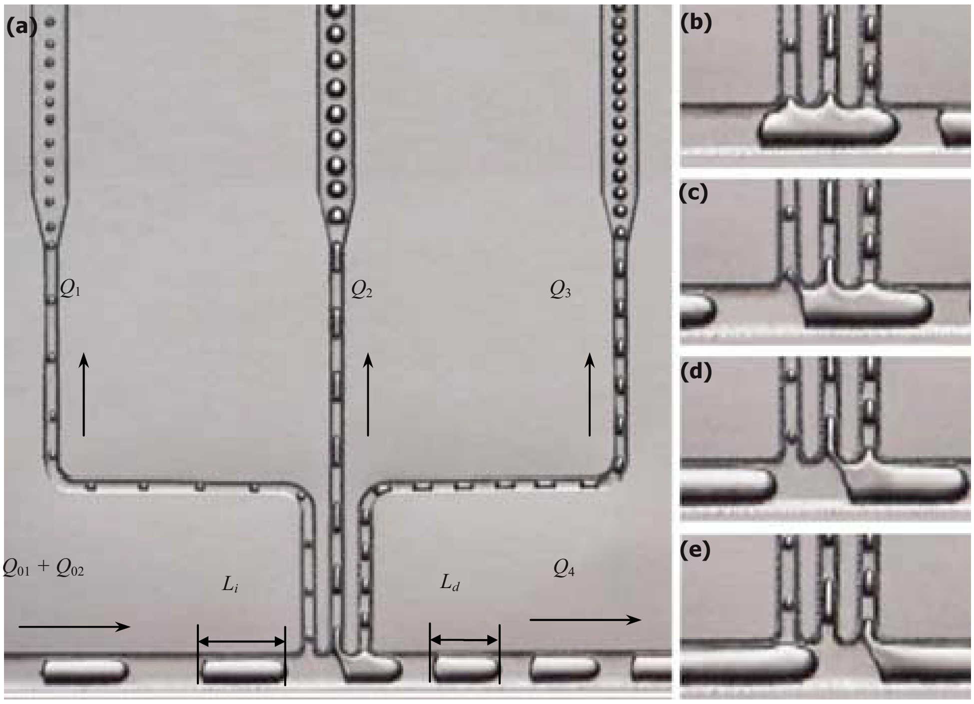
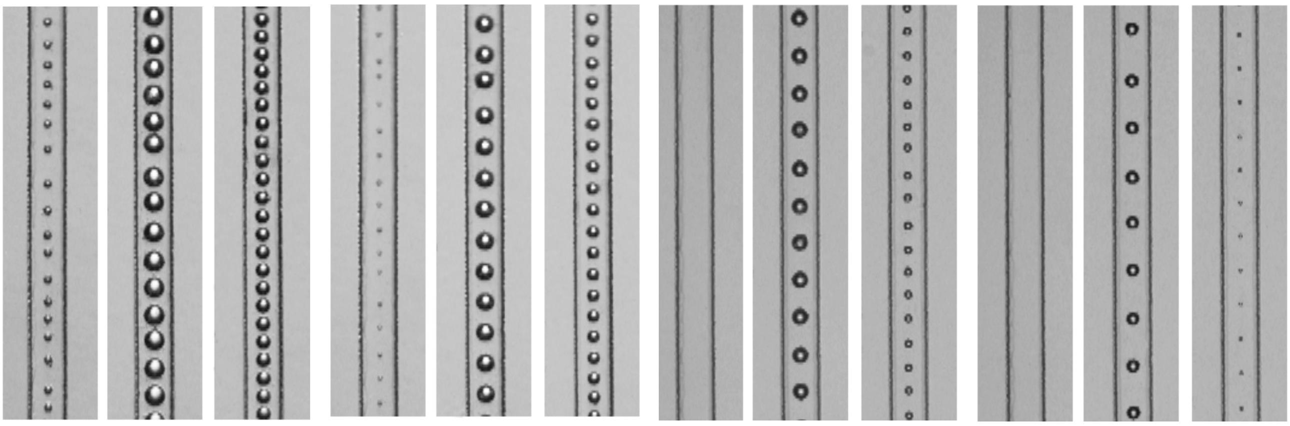


Figure 3: Micrographs of (a) the droplet splitting system, (b-e) the sequence of plugs breakup in the multiple-splitting branch.

Figure 3(a) shows the micrograph of the droplet splitting system. The chip is made of polydimethylsiloxane (PDMS) using standard soft lithographic technique. The width of the main channel is 100 µm, and that of the branch channels is 40 µm. The height of all structures is 70 µm. The branch channels connected with wider channels (width is 100 µm) for observing droplet array, from left to right are: channel 1, channel 2 and channel 3. DI water and immersion oil with 2wt% SPAN 80 are used as the dispersed and the continuous phase, respectively. DI water and immersion oil are injected continuously by syringe pumps (NE-1000, New Era). The water-in-oil plugs are generated at the T-junction. As an isolated plug reaches the splitting junction, the generation of three droplet flows is shown in Fig. 3 (b-e). When the plug passes through one of the side-branches, the plug develops a short finger into the branch channel. The finger grows



d= 22 µm d= 48 µm d = 36 µm d= 13 µm d = 44 µm d= 30 µm d = 0 d = 38 µm d = 17 µm d = 0 d = 33 µm d = 12 µm

(a) (b) (c) (d)

Figure 4 : droplet flows tuning in the three branch channel with different initial plug size.(a) 303 µm,(b)155 µm, (c) 130 µm and (d)112 µm. From left to right: channel 1, channel 2 and channel 3.

until the plug leave the channel open. The bride linking the finger to the main part of the plug eventually breaks up, giving rise to a separate plug. When the generated plug flows down to a sudden expansion of the microfluidic channel, it is transformed into circular droplet as shown in Fig. 3(a).

Figure 4 shows different droplet sizes generated with different initial plug sizes. Larger initial plug generates larger droplets in the branch channels. The droplet size ratio between the three channels is decided by the flow resistances as shown in the simple resistive circuit model. The flow resistance should be considering the pressure drop of a non-compressive Newtonian fluid in a microchannel with rectangular cross section. The higher resistance created by longer channel, thus a lower volumetric flow rate can be deduced. That means shorter channels can generate larger droplet. As shown in Fig. 3(a), channel 2 is the shortest. As a consequence, the droplets in channel 2 are the largest. Although channel 1 and 3 are the same length, the resistances of them are different due to their different position in the system. Resistance R_4 and R_5 in the resistive circuit model should be considered. The smaller resistance of channel 1 gives it a smaller size of droplets. However, the droplet in every single channel are found to be monodispersed with only 1% variation in size.

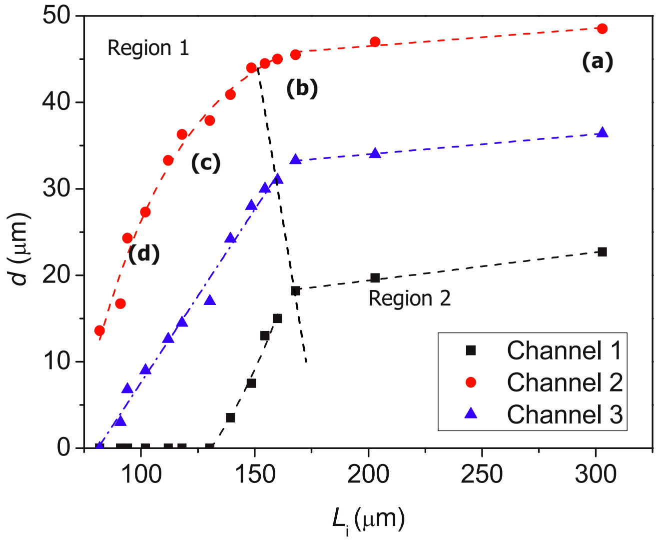


Figure 5: Relationship between the initial length of plug and diameter of droplets in branch channels.

Figure 5 shows the relationship between the droplet size and the length of initial plug. As we discussed above, the droplet size can be continuously changed by the adjustment of the initial plug size. For example, when the plug size is decreased from 303 μm to 80 μm, the diameter of droplets in channel 2 is changed from 48 μm to 13 μm. However, the size decreasing rate is not a constant. As shown in Fig. 5, the relationship between the droplet size and the length of initial plug can be divided into two regions. In Region 1, when the plug length is smaller than the junction length (160 μm), the droplet size increases with larger plug size at a gradient of 0.4. However, in Region 2, when the plug length is larger than the junction length, the size increment of the droplet is limited at a gradient of 0.02. This is because limited liquid flows into the branch channels when the plug blocks the three branch channels. When the plug is smaller than 38 μm, no droplet can be found in channel 1. And the droplets in channel 2 is disappeared when the plug size reaches 80 μm. When the plug size is reduced to 70 μm, no splitting effect is observed.

CONCLUSIONS

In conclusion, side-branch structure is designed to generate multiple flows of highly monodispersed droplets with polydispersity of 1%. It can produce droplet with small size (< 2 μm) which are difficult to be generated with usual microchannel emulsification techniques. The advantages of the microfluidic chip can provide simple, high efficient way to generate droplets with multiple sizes concurrently using a single side- branch structure.

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CONTACT

*A. Q. Liu, Tel: +65-6790 4336; Fax: +65-6793 3318; Email: eaqliu@ntu.edu.sg